the future. We are now working on phase-weighted stack algorithms [3], in order to adapt them to the processing sequences of wide-angle seismics.

5. Acknowledgement
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Signal processing techniques applied to seismic signal detection

S. Ventosa (1), C. Simon (1), M. Schimmel (2)

(1) Unitat de Tecnologia Marina,
Pg. Marítim de la Barceloneta 37-49
08003 - Barcelona - Spain
Email: sventosa@utm.csic.es.
(2) Instituto de Ciencias de la Tierra 'Jaume Almera'
08028 - Barcelona - Spain

1. Introduction
Wide-angle reflection/refraction seismics (WAS) is one of the most commonly used techniques to determine the structure of the Earth's crust. The acquisition system includes a number of energy sources and receivers located at increasing distances from the sources that record both the reflections and the continuous refractions of the seismic waves propagating into the medium. Data are represented in the so-called record sections, which display recordings of the different sources registered by a given receiver (or vice-versa) into offset-travel time diagrams.

Useful seismic phases present in the record sections are usually masked by different types of noise, which may be caused by the instrument (electronic noise, quantification ...), by the environment (ship noise, cetacean, sea wave course, currents ...), or even by the signal itself (higher order reverberations and scattered signals which obscure later arriving prominent phases). In order to obtain as much of the valuable information contained in the record sections as possible, it is necessary to process the collected data in order to either (1) improve the signal to noise ratio, or (2) remove or attenuate some well characterized phases, such as the water wave or the first reverberations.

Most of existing techniques to improve the signal to noise ratio assume that noise is stationary and Gaussian. However, this is usually not the case, so it is necessary to apply alternative techniques for an improved signal detection. These methods are usually based on nonlinear signal processing techniques that make use of other signal properties that are more robust against outliers, such as median estimators.

2. Polarization filters
One of the techniques used in order to distinguish signal form noise are filters based on the degree of polarization [1-2]. [1] and [2] define a signal by an arbitrary but constant polarization throughout the course of the signal. This means that these filters use the complete wavefield, i.e., the three components of the geophone, to measure the variation of polarization along traces regardless its category (lineal, circular or elliptic) or direction.

According to the characteristics of the signal to process, we have considered two related techniques: one works in the time domain, whereas the other one works in the time-frequency domain through a windowed Fourier Transform (e.g., Short Time Fourier Transform, S-Transform). Alternative approaches, such as the Wavelet Transform can be employed.

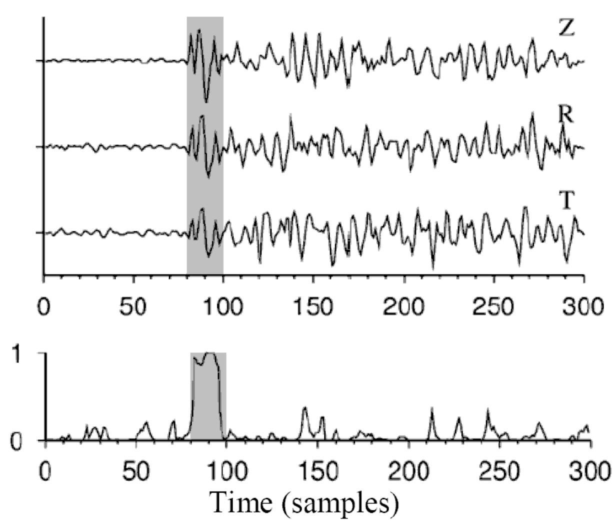

Figure 1: Three-component test data and its degree of polarization. The polarized signal is indicated by the grey background.

The approach we present here can be separated in three main steps. First, we estimate the instantaneous polarization attributes of the recorded signal. In the time-domain method, analytic signal properties are used [3], while in the time-frequency domain method we use spectral signal properties [4]. The instantaneous parameters are used to compute the degree of polarization in a second step, in order to measure the variation in direction of the polarization vector, figure 1. Finally, a mask is formed by this measure and applied to the record section. It allows attenuating noisy parts that are poorly polarized without affecting polarized areas.

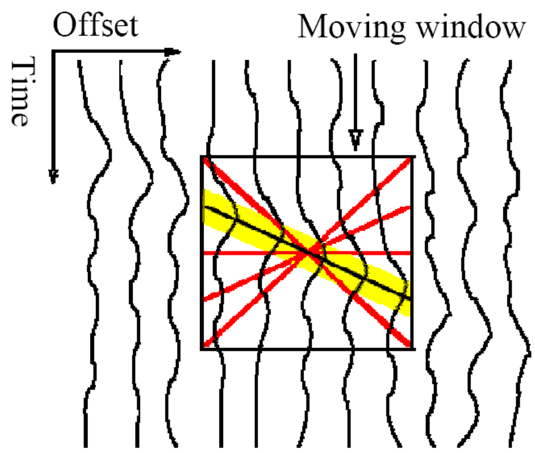

Figure 2: Spatial averaging window. The window is a function of time, trace offset and slowness.

If the density of traces is high then it is possible to use correlations between different traces and the directivity of waves to reduce the noise level by means of spatial averaging filtering [1], figure 2.

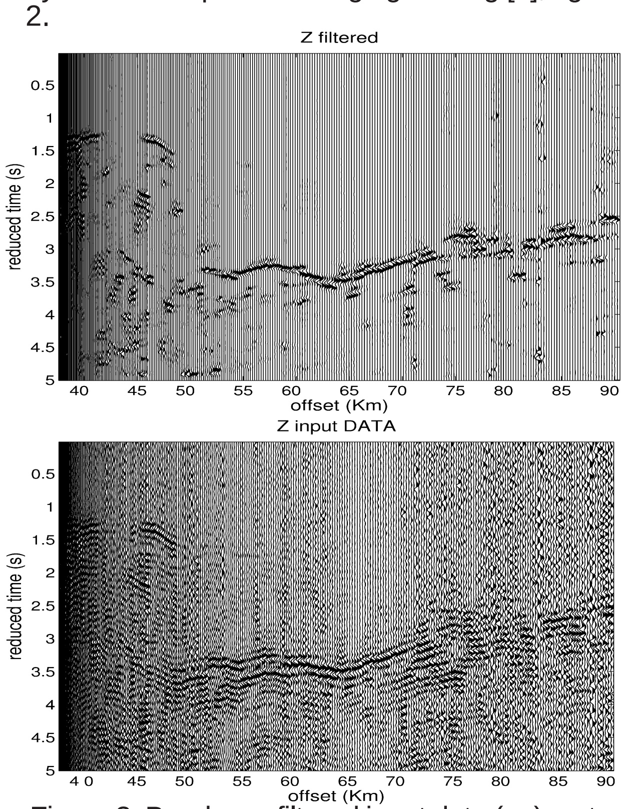

Figure 3: Bandpass filtered input data (up), output of polarization filter (down).

3. Results and Discussion

An example of application on real data take from Ligurian Sardinian wide-angle seismic profile acquired during 1995 in the Western Mediterranean, figure 3.

We reprogrammed the filters considering specially the calculation speed and memory usage to enable an efficient processing of huge data volumes and to include them into the WASPAR (Wide-Angle reflection/refraction Seismic data Processing And Representation) platform [5]. These processing tools developed to date can be used to emphasize some specific type of waves, remove unwanted phases, such as water reverberations and other multiples, or to extract a well characterized wave from the rest of the record section.

4. Acknowledgement

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